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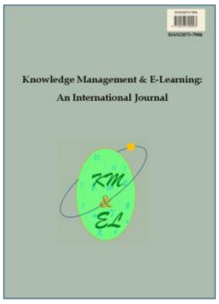
Citation for published version:
Samarakou, M, Fylladitakis, E, Fruh, W-G, Karolidis, D, Hatziapostolou, A, Athinaios, S & Grigoriadou, M 2016, 'Evaluation of an intelligent open learning system for engineering education', *Knowledge Management and E-Learning: an International Journal*, vol. 8, no. 3, pp. 496–513. <http://www.kmel-journal.org/ojs/index.php/online-publication/article/viewArticle/404>

Link:
Link to publication record in Heriot-Watt Research Portal

Document Version:
Publisher's PDF, also known as Version of record

Published In:
Knowledge Management and E-Learning: an International Journal

Knowledge Management & E-Learning



ISSN 2073-7904

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Recommended citation:
Samarakou, M., Fylladitakis, E. D., Karolidis, D., Früh, W.-G., Hatziapostolou, A., Athinaios, S. S., & Grigoriadou, M. (2016). Evaluation of an intelligent open learning system for engineering education. *Knowledge Management & E-Learning, 8*(3), 496–513.

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Evaluation of an intelligent open learning system for engineering education

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Abstract: In computer-assisted education, the continuous monitoring and assessment of the learner is crucial for the delivery of personalized education to be effective. In this paper, we present a pilot application of the Student Diagnosis, Assistance, Evaluation System based on Artificial Intelligence (StuDiAsE), an open learning system for unattended student diagnosis, assistance and evaluation based on artificial intelligence. The system demonstrated in this paper has been designed with engineering students in mind and is capable of monitoring their comprehension, assessing their prior knowledge, building individual learner profiles, providing personalized assistance and, finally, evaluating a learner's performance both quantitatively and qualitatively by means of artificial intelligence techniques. The architecture and user interface of the system are being exhibited, the results and feedback received from a pilot application of the system within a theoretical engineering course are being demonstrated and the outcomes are being discussed.

Keywords: Interactive learning environment; Student profiling; Computer-assisted education; eLearning; Online learning

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1. Introduction

The technological developments of the past few decades, particularly the high adoption rate of home computers and the World Wide Web (WWW), allowed for the development of teaching and learning approaches that were implausible a few decades ago. One such development is Open Learning Environments (OLEs), which firstly appeared about two decades ago, alongside the rising adoption rates of home computers (Hannafin, Land, & Oliver, 1999). Due to the great global adoption of the WWW, the interest on OLEs exploded during the past few years (Van Vuren & Henning, 1998; Mott & Wiley, 2009; Salmi, Kaasinen, & Kallunki, 2012; Allison & Miller, 2012; Simpson, 2013; Wong, Greenhalgh, & Pawson, 2010), leading to the development of numerous systems, based on a variety of educational approaches and for various educational applications (Rehani & Sasikumar, 2002; Sorenson & Macfadyen, 2010; Tsaganou & Grigoriadou, 2008; Niu, 2002). Higher education institutions are increasingly moving towards the WWW for the delivery of material and or courses (Kim & Bonk, 2006), with particular interest in OLEs (McAndrew, Scanlon, & Clow, 2010).

In computer-assisted education, the monitoring and continuous assessment of the learner is crucial, not only for an effective educational assessment but also for the capability of the system itself to adapt to the needs of the learners, otherwise the delivery of personalized education would be ineffective (Dimitrova, 2003; Niu, 2002; Wiggins, 2012). Monitoring and assessing the performance of learners during class is a challenging task, particularly in the case that it has to be performed in real-time classroom conditions. This is especially true during laboratory courses in engineering education, where the "one size fits all" assessment approach that bases the entire process on the end result of the exercise has proven to be highly ineffective, depriving the learners from the possibilities of adaptation and customization that are critical in engineering education (McConnell, 1999; Tsai, 1999; Hofstein & Lunetta, 2004). The role of the laboratory courses in engineering education is critical and, therefore, OLEs developed with the intent to be used for laboratory courses ought to be capable of their inclusion and effective delivery (Feisel & Rosa, 2005).

In this paper we present the Student Diagnosis, Assistance, Evaluation System based on Artificial Intelligence (StuDiAsE), an open interactive learning system based on the text comprehension theory by Denhière and Baudet (1992) and dialogue theory (Collins & Beranek, 1986). To this date, similar learning environments that can generate a student model using linear numerical techniques, usually based on just the result of a single diagnostic test (Gasparinatou & Grigoriadou, 2011; Melis et al., 2001). It is difficult to use the output or the personalized feedback of such learning environments for the accurate classification of students according to the four basic educational dimensions (Felder & Silverman, 1988). This is especially problematic in the case of engineering education, where the student classification and assessment should not be based on the result of text activities only. However, more advanced assessment algorithms do exist for adaptive learning environments today, which can be used to develop innovative and formidable learning tools (Tsai, Tseng, & Lin, 2001; Samarakou, Papadakis, Prentakis, Karolidis, & Athineos, 2009).

StuDiAsE has been designed with engineering students in mind and is capable of monitoring their comprehension, assess their prior knowledge, build individual learner profiles, provide personalized assistance and, finally, evaluate a learner's performance both quantitatively and qualitatively through artificial intelligence (Tsaganou, Grigoriadou, & Cavoura, 2004; Grigoriadou & Tsaganou, 2005; Samarakou et al., 2013b). In the following chapters, we will discuss the architecture of the system, present the educational environment and display the feedback results from the application of a pilot course.

2. System architecture

Diagnosing the cognitive capability of the learner is crucial for the development of adaptive systems, making the monitoring and evaluation of the learners a critical research subject about OLEs (Bull & Kay, 2005; Hansen & McCalla, 2003; Nicol & Macfarlane-Dick, 2006). StuDiAsE is a dialogue-based open learning tool, designed to monitor the comprehension of learners, assess their prior knowledge, build individual learner profiles, provide personalized assistance and, finally, evaluate their performance by using artificial intelligence (Tsaganou, Grigoriadou, & Cavoura, 2004; Grigoriadou & Tsaganou, 2005; Samarakou et al., 2013b).

To implement the educational environment, the system is using C# and MS .net framework 3.5 technologies, while various parts that were required were implemented via custom web user controls and web services. The database used is Microsoft SQL-Server 2008 as the HTTP server in IIS 7. The online version of the pilot system is accessible via the following link: http://pclab.et.teiath.gr/studiase/index.en.htm.

The system architecture is divided into three levels. At the lowest level, necessary entities are modeled to represent the components of the system. This level essentially implements the Database Access Layer of the 3-tier architecture. The middle layer includes the subsystems that are necessary to implement the logic operation of the system. The design is such that the subsystems can be used independently. This level implements the Business Logic Layer of the 3-tier architecture. Finally, the upper level is the level that users interact with and essentially is the UI (User Interface). This level essentially implements the Presentation Layer of the 3-tier architecture.

The upper level is split into three sublevels: the learners sublevel, the educators sublevel and the administration sublevel. Learners should be able to access the system in a classroom or through the internet. A user-friendly interface helps the learners to easily and freely navigate throughout the educational materials, perform activities selected or created by their educators, realize their own capabilities and weaknesses and improve their educational profiles. The interactive system seeks to cause them to reflect on their answers, enhance their motivation and guide them to acquire better scientific thought. Educators can access options regarding the modification and or insertion of educational material, as well as options concerning the assessment subsystem. If a learner has already performed actions and or tests, the educator can also view them and their results.

The middle layer includes the five basic subsystems of StuDiAsE, which are:

1. The monitoring subsystem
2. The logging subsystem
3. The profiling subsystem
4. The modeling subsystem
5. The evaluation subsystem

Fig. 1 displays how these subsystems are linked to the main database and between each other. The operation of these subsystems is imperceptible by the users. The profiling, modelling and evaluation of the learners is being performed through the use of artificial intelligence and, specifically, fuzzy logic (Samarakou et al., 2009; Chrysafiadi & Virvou, 2012). Detailed information on the five subsystems of StuDiAsE may also be found in (Samarakou et al., 2014).

The monitoring subsystem monitors and logs the actions of the users. The objective of the subsystem is the logging of sufficient data, in terms of both quantity and quality, which can be then used to build a profile for the learner and provide personalized material and assistance. Information can be either static, such as the name of the learner and specific settings, as well as dynamic, such as the time spent on each activity and the number of questions that have been answered. The logging subsystem operates in parallel with the monitoring subsystem, recording the user data during the educative session and storing it to the database, where it can then be accessed and used by the other subsystems.

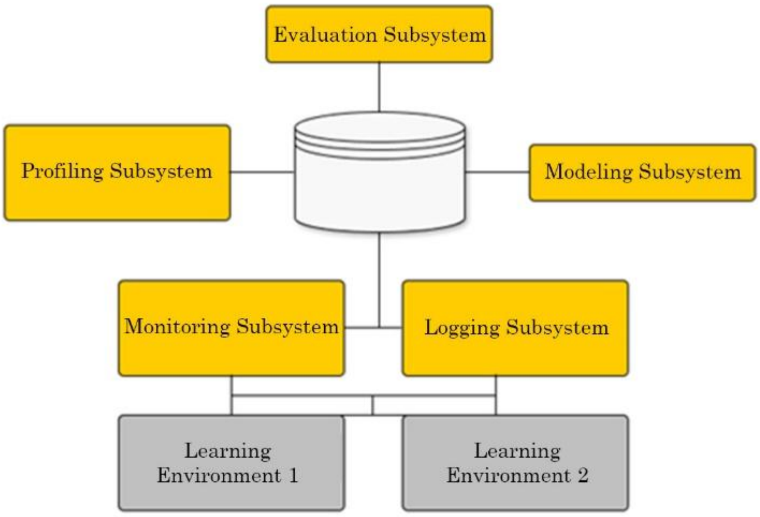

Fig. 1. The structure of StuDiAsE

The profiling subsystem extracts the original cognitive profile of a learner, which represents the prior knowledge on the selected topic based on the options that have been selected by the learner. The status of the learner can then be assessed via specific characteristics, such as level of prior knowledge, knowledge gaps, contradictions, learning style, attitude during the study and his willingness to participate. The aim is to study the characteristics of the learner that are important for personalization of the educational process. Furthermore, the profiling subsystem also seeks possible ways to engage learners in the diagnostic process, which aims for the proper generation of a cognitive profile. Using artificial intelligence and by exploiting the data logged during the educational process, StuDiAsE is capable of deriving personalized learner profiles. These profiles can then be used to assess the capabilities and weaknesses of a learner, as well as for their evaluation (Bai & Chen, 2008; Stathacopoulou, Grigoriadou, Samarakou, & Mitropoulos, 2007).

The modeling subsystem evaluates and composes the knowledge that the system has on the learner. It includes the rules for the processing of the available results and data acquired by the monitoring subsystem, for every learner, through which the system creates a representation of the learner's knowledge on each educational subject. Finally, the evaluation subsystem is using the learner's model and multiple data inputs, such as the data recorded by the monitoring and logging subsystems, and utilizes artificial intelligence techniques in order to reach a personalized assessment. StuDiAsE is specifically using fuzzy logic techniques, combining sets of rules with customized information extracted from experts (Samarakou et al., 2013a).

3. Interface

The developed educational tool is essentially aimed at two categories of users: educators - teachers and learners - students. Educators can create dynamic activities for learners - students in order to understand texts related to various subject areas. They may also expand the tree of activities by adding their own. For the creation of these activities, the educator is being led systematically by the interface. Each activity includes a properly structured text into paragraphs, which is accompanied with corresponding comprehension diagnostic questions from several categories.

StuDiAsE essentially offers five user interface usage scenarios. There are the theories and laboratory sections for learners, the same sections for educators, and a fifth section that is the administration section for educators with administrator access. In this paper, we will present the theory part of these sections as they have been developed for the needs of a specific engineering class, the "Heat Transfer" section of the "Foundations of Energy" module that is part of the MSc in Energy programme, which is being taught in the T.E.I. of Athens in collaboration with the school of engineering and physical sciences of Heriot-Watt University.

Fig. 2 displays the introductory page that all users will be greeted with when they enter the educational environment. From this page, the user is called to choose whether he or she wants to enter the section with the theoretical courses or the section with the laboratory courses. Once either option is selected, the user will be asked to log into the system. Learners and educators alike log in from this section and can create new accounts as well. All new accounts that are being created are treated as learner accounts, unless the administrator changes their access privileges.

Fig. 2. Introductory page

The learner user interface is split into two main sections; the theory and the laboratory. Once the learner selects a section, he or she will be asked to log in. The home page of the learner's theory section user interface can be seen in Fig. 3. The learner can select a course, view completed courses and activities, as well as check his or her progress and cognitive profile when enough data has been acquired. The suggested path for a learner to follow is to first take an initial diagnostic test, with which the system will assess the initial cognitive profile of the learner, and will then offer a personalized suggestion regarding which educational text to study in order for the learner to improve his or her cognition on the subject. Afterwards, the system will propose the completion of a second diagnostic test that will assess the progress of the learner. However, if the learner does not wish to follow this path, he or she can freely choose other options, although the system may not be able to perform certain functions if the suggested path has not been followed. For example, if a learner decides not to take the initial diagnostic test, the system will suggest the relational text type and will not be able to assess the level of educational improvement of the learner.

Fig. 3. Learner's user interface, theoretical section

The tasks of student profiling and personalized feedback are being performed by the profiling subsystem, using fuzzy logic AI and based on the comprehension theory of Denhière and Baudet (Denhière & Baudet, 1992; Samarakou et al., 2013c). Note that even though the system will propose a specific type of text after the completion of the diagnostic text, the learner is free to choose from any type of text available (relational, transformative or teleological). After selecting and studying a text, the learner can start an assessment activity that is based on the exact type of text he or she just studied. There may be any number and type of questions as the educator who compiled the particular section saw fit. The learner may choose to skip a question, revert to a previous question and even seek additional assistance on a specific question. The latter is being done by clicking the "?" icon to the right side of the interface, in which case a supplementary text will appear in the teal box to the right. This option is not available during the diagnostic tests. Although the pilot system presented in this paper has such options disabled for the time being, the logging and monitoring subsystems can also log information regarding the user's actions and preferences, such as the time to answer a question, the number of times that he or she reverted to previous questions and or requested help, etc. Such information can then be used by other subsystems to improve the quality of the feedback and assessments. Fig. 4 displays the user interface while the learner is taking an activity after reading an educational text.

Fig. 4. Learner's interface during an educational activity

After the learner completes the second diagnostic test, the system will present his or her assessment results. If the learner followed the suggested path, performing the initial diagnostic test, then any of the three available educational activities and finally the second diagnostic test, the system will also display his or her initial and final cognitive profiles, as well as the specific improvement on each type of educational text (Relational, Transformative or Teleological). Fig. 5 displays such an assessment, of a hypothetical learner who performed the first diagnostic test, then chose a transformative text and completed the associated activity and, finally, took the second diagnostic test as well.

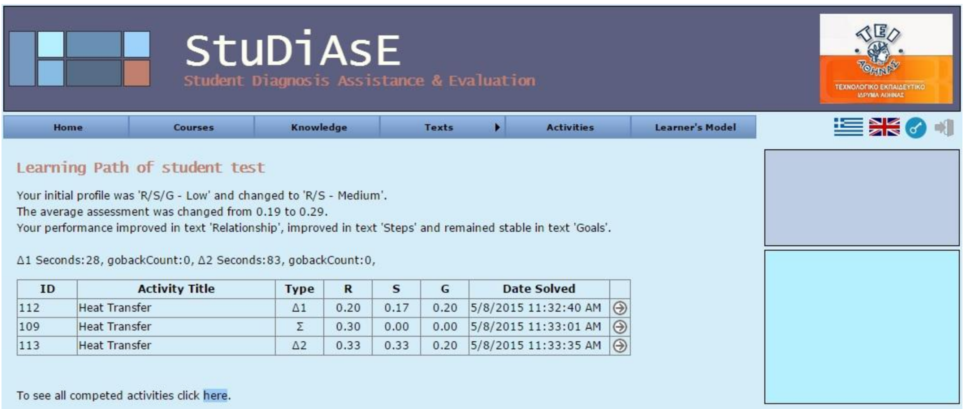

Fig. 5. Assessment results and the learner's cognitive model

Similarly with the learner user interface, the educator user interface is also split into the theory and the laboratory sections. Once a section is selected, the user will be asked to log in. If the username/password corresponds to an account with educator access, the user is directed to the educator's user interface home page (Fig. 6). The home page of the educator allows the user to access the management pages of courses, activities, texts and questions. It is up to the administrator to limit the capabilities of an educator's account if that is deemed necessary, otherwise the educator can insert a virtually infinite amount of educative material into the system. It is also possible to give certain educator privileges to accounts, such as the ability to manage activities and questions but not courses, allowing the creation of educator accounts that can essentially only work within their own course.

Fig. 6. Educator's home page

4. Results and discussion

In order to assess the functionality, abilities, capabilities and shortcomings of the developed open learning environment, a pilot application was arranged for the students of the MSc in Energy programme. A short course on the topic of Heat Transfer was developed as part of the Foundations of Energy module, and access was given to students as optional assistance material. After using the system, the students were asked to fill in a questionnaire (Appendix A, Table 1).

Fifty students participated in this study. All of the students followed the path proposed by the system; they first took a diagnostic test that has been used to create their initial cognitive profile, then the system provided personalized feedback to each one of them and, after the students completed going through the extra educational material provided by the system, they performed a second diagnostic test, with the system generating the final cognitive profile of each student. The same process was also performed by an expert in parallel, in order to identify any flaws in the diagnostic and or evaluation processes. For this pilot study, only quantitative assessment rules were implemented. Qualitative rules (total time, number of times the user sought help, etc.) were disabled.

As it can be seen from the results of the survey, the evaluation of the curricular, didactic and education methodology is highly favorable. The students mainly voiced concerns on the study time and the information on prerequisite knowledge and skill required for the effective use of the educational environment. Such an outcome was expected from this pilot application, as the students were called upon to participate for just one course of a single module, without sufficient information about the educational tool. Still, as it can be seen from the second section of the survey, almost the entirety of the students was positive on the design and layout of the contents.

The students voiced some concerns about the user interface, mainly regarding the use of icons/buttons and the on-screen information. Modifications have been or are planned to be performed on the version that was used for this pilot study, including tooltips and guidelines. In addition, considering the student's responses to question 4.5, a quick start user guide is being composed, in order to help with the quick and effective use of the user interface by the students.

As for the functionality of the educational software, the responses of the students were mixed. The simplicity and stability of the resource-lightweight educational tool is evident by the responses of the students. Rightfully, the students expressed concerns on the undoing of user actions and the possibility to download learning material, as these options were disabled in the version that was used for the means of the pilot study. The students also expressed concerns on the security that the system offers, noting that their usernames and passwords were "too easy to guess". However, this obviously occurred because the students were given pre-generated accounts with simple username/password combinations and were not informed of the ability to create their own accounts and passwords at the time of this pilot study.

For educators, the inclusion of the open learning environment had multifaceted benefits. The tool assisted the educators with their assessment of students, their classification according to Felder's theory and with the diagnosis of educational issues (Felder & Silverman, 1988). From the assessment results, the educator can easily identify holistic learners, who had simultaneous advancement on all fronts, from sequential learners, who their progress came in small incremental steps. Students who are strongly visual can be identified as well, from the ratio of their performance when the feedback includes multimedia to that of when the feedback consists solely of written explanations. Identifying visual from verbal students early and personalizing the feedback they receive can be critical for their long-term performance. It also proved a very effective way to recognize students who can perform very well but their character limits their social contact in class, helping in the identification of reflective students, who prefer individualized study and self-reflection to traditional educational methods. The only major drawback was the disproportional amount of time required to develop and insert the educational material for just a single course. However, this needs to happen only once for any given course/subject, which can then be updated whenever necessary. Therefore, for an established educational course, the time required to develop and insert the material is manyfold lower than the time that the use of such a system will ultimately save.

Educationally, the improvement of the students that used the educational tool for this pilot study was very significant. From the users that participated in the study, the average text comprehension improvement was 34% on relational texts, 54% on transformative texts and 60% on teleological texts. The median improvement between the initial diagnostic test and the final diagnostic test was nearly 52%. Furthermore, the course has an obligatory written assessment that all students partaking it have to perform;

the scores of the students who participated in this pilot study were higher by about 17% over the students who did not.

5. Conclusion

In this paper, we demonstrated the Student Diagnosis, Assistance, Evaluation System based on Artificial Intelligence (StuDiAsE), an open interactive learning system based on the text comprehension theory. By using logging/recording functions and artificial intelligence rules, StuDiAsE can be used to identify, assess and improve the comprehension of students. By treating each user as a singular entity and in conjunction with proper rules, compiled by an educational expert, StuDiAsE can define the strengths, weaknesses and individual characteristics of each student, provide personalized feedback and improve the engagement of the student on the educational process. This processing helps to overcome the "one size fits all" approach that is the rule in engineering education today.

During the pilot application of StuDiAsE, we identified multiple advantages. For students, the proposed environment is an engaging educational tool that will automatically identify their weaknesses and seek to improve them. As the student uses the educational tool, even if only out of curiosity, StuDiAsE generates his or her educational profile and seeks to improve his or her skills via personalized feedback. This approach proved to be particularly effective on unmotivated students, who would otherwise not study sufficiently or at all, as the scores of average and below-average students were those that improved the most during this pilot course. There are distinct advantages for educators as well, with the most apparent being that the proposed system is simple and time-wise effective. The time to develop the material required for each course may be significant at first but it is greatly lower than the time required to manually assess the performance of each individual student over the lifetime of the course. Despite these numerous advantages, we also identified a number of weaknesses, such as the necessity of the students to be able to undo certain actions. These weaknesses were addressed after the research team received the feedback from the students participating in the pilot study or will be addressed in future versions of StuDiAsE.

Assessment provided by StuDiAsE is multidimensional and may implement both quantitative and qualitative factors. Aside from the number of correct, wrong and unanswered questions, qualitative factors can also be implemented into the assessment. These can be the choice of the additional educational material, if the user skipped the additional material entirely and proceeded to the test, the time taken to complete each activity, the number of times that the user requested assistance, etc. However, even with just quantitative assessment based on the number of correct, unanswered and wrong answers, the pilot study presented in this paper proved that StuDiAsE could be highly effective and adaptive to the needs of engineering students.

Future research will be performed to assess the efficacy of qualitative evaluation, the capability of the system to include laboratory courses effectively and the possibility to replace classic taught modules partially or entirely.

Acknowledgements

This research has been co-funded by the European Union (European Social Fund) and Greek national resources under the framework of the “Archimedes III: Funding of

Research Groups in TEI of Athens" project of the "Education & Lifelong Learning" Operational Programme.

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Appendix A

Table 1
Evaluation questionnaire for students/learners

Criteria	**Agree**	**Somewhat agree**	**Neither agree or disagree**	**Somewhat disagree**	**Disagree**
EVALUATION CRITERIA OF THE CURRICULAR, DIDACTICS AND EDUCATION METHODOLOGY					
The environment covers more than one subject areas related to the learning goal?	10%	76%	10%	4%	0%
Is there consistency regarding the terms and symbols used throughout the contents?	96%	4%	0%	0%	0%
The construction and organization of information is apparent?	80%	16%	4%	0%	0%
Educational materials are properly organized and structured in modules?	44%	40%	8%	6%	2%
Are modules-submodules presented in a correct sequence?	40%	56%	2%	0%	2%
The student is being kept informed of the study time by the material.	0%	10%	42%	30%	18%
There is information on the prerequisite knowledge and skills required for effective use of the educational environment?	0%	0%	28%	56%	16%
The student has the ability to select educational material of his/her choice.	72%	20%	0%	8%	0%
The presentation of the contents stimulates the interest of the student.	78%	10%	8%	2%	2%
EVALUATION CRITERIA ON THE DESIGN AND LAYOUT OF THE CONTENTS					
The learning environment is suitable for use by each individual student?	32%	50%	10%	6%	2%
The educational environment provides the student with alternative navigation paths depending on his/her personal needs?	54%	26%	16%	4%	0%
The presentation of concepts helps the student to understand and consolidate them?	72%	24%	4%	0%	0%
The educational environment leads students to predefined objectives and results?	58%	38%	2%	2%	0%

A student may repeat a learning path according to their needs?	42%	58%	0%	0%	0%
The students are aided to follow different educational paths depending on the level of knowledge or skills they have?	78%	20%	2%	0%	0%
EVALUATION OF THE USER INTERFACE					
The texts are legible and written in language simple and understandable?	40%	24%	6%	18%	12%
The vocabulary is rich and homogeneous?	32%	50%	14%	4%	0%
Grammar and syntax are consistent?	20%	74%	6%	0%	0%
Messages on transition from section to section are clear and understandable?	76%	20%	4%	0%	0%
Quantity and density of the information on the screen is functional?	60%	14%	24%	0%	2%
The use of icons, buttons and menus is obvious.	24%	34%	30%	8%	4%
Is it possible for the student to control the flow of information?	32%	28%	34%	4%	2%
It is easy to navigate back and forth?	94%	4%	2%	0%	0%
There is always the option of returning to a home menu.	98%	2%	0%	0%	0%
It is possible to logout from the program from any point.	100%	0%	0%	0%	0%
It is possible to return to the last point accessed, without data loss?	78%	14%	6%	0%	2%
EVALUATION CRITERIA ON THE FUNCTIONALITY OF THE EDUCATIONAL SOFTWARE					
The educational environment informs the student - user about the consequences of various actions and choices that may lead to impairment of the application?	24%	58%	14%	4%	0%
The environment allows the undoing of user actions or choices?	0%	2%	8%	16%	74%
The possibility of failure to complete a process due to an environment error is minimal or non-existent?	58%	40%	0%	0%	2%

The messages displayed to the user are simple and understandable?	56%	42%	2%	0%	0%
The offered assistance covers how to use the environment?	18%	36%	14%	30%	2%
Is the response time of basic functions of the educational environment within reasonable limits?	98%	2%	0%	0%	0%
Is it easy for students to use the basic functions of the educational environment?	94%	4%	2%	0%	0%
Protection is provided against users that do not have permission to access portions of the educational environment and data.	8%	12%	24%	54%	2%
It is possible to collect and transfer (download) learning material?	0%	0%	0%	20%	80%